NASA/CR-97- 206350

24th November 1997

FINAL

NAG 2-504 Pioneer Venus Orbiter Ultraviolet Spectrometer : Operations and Data Analysis

7N-19-CR

Final Technical Report

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Contents :

1. INSTRUMENT PERFORMANCE

a) Narrative

The Pioneer Venus spacecraft orbited Venus 5,055 times between 4th Decemder 1978 and 6th October 1992, before entering Venus' atmosphere and burning up on the latter date. On 255 of these orbits, science operations were suspended because of superior conjunction (Venus' proximity to the Sun as seen from Earth). Of the remaining 4800 orbits, about 85% yielded good-quality OUVS science data; 15% were lost to various problems. including loss of uplink (commands) to and downlink (data) from the spacecraft, errors in commanding OUVS, and one or other of the two instrument anomalies mentioned below.

OUVS showed one expected change in performance over the mission, a decrease in sensitivity in the long-wavelength F detector. It also showed two kinds of anomalous behaviour, both unexpected but neither causing any significant loss in science return. These were : an instability in the diffraction grating control mechanism, and a failure of the data-handling system under certain circumstances.

b) Decrease in long-wavelength sensitivity.

Because of Venus' high UV albedo and its location relatively close to the Sun, the repeated long-wavelength observations required to monitor SO2 near the cloud-tops led to fatigue in the F-channel photomultiplier, manifest as a reduction of sensitivity by a factor of 5-10. Such fatigue is a well-known phenomenon and was expected. It had little effect on the quality of the datside SO2 observations, since the signal remained high; but it significantly reduced the signal-to-noise obtained during observations of the nightside nitric oxide emissions, where the signals were much lower. Nevertheless, these nightside emissions were successfully measured throughout the mission.

c) Grating Control Instability.

Beginning soon after orbit insertion in 1978, it was found that the diffraction grating control units were unstable. Certain grating positions, ie certain wavelengths, could not reliably be maintained for the periods (minutes through hours) necessary to complete the desired observations. Both of the instrument's two Grating Control Units displayed this behaviour. In most cases, an adjacent grating position could be found that was stable and that allowed the observations to be made. In a few cases, the occasional (about once in ten) loss of usable data had to be accepted. The scientific return from the instrument was not significantly affected. The design of the GCU was improved after the PV instrument was built, and the improved units flown on later missions (Galileo, Solar Mesosphere Explorer) did not exhibit this behaviour.

d) Data handling problem

In flight it was discovered that the logic controlling the delivery of instrument science words to the spacecraft telemetry system failed under two situations : when the telemetry system asked for OUVS science words faster than the instrument generated them, and when it did not ask for them frequently enough. In both cases, all-zero words appeared in the telemetry stream until a new set of commands removed the problem. Because the rate at which the OUVS generated words could be controlled by command, and because the problem only arose under relatively rare combinations of downlink telemetry rate and telemetry format, the problem could be avoided most of the time. The design flaw that led to the problem (a signal timing problem in the instrument control logic) was soon identified and was easily eliminated from later instruments.

2. MAJOR SCIENTIFIC RESULTS.

a) The nightside of Venus was found to radiate in the ultraviolet. The emissions were shown to emanate from nitric oxide near 115 km, arising from the radiative association of atmos of nitrogen and oxygen. Because these atoms are produced only on the dayside, the NO emissions proved to be a valuable tracer of the strong day-to-night winds that blow in Venus' upper atmosphere.

b) The spectrum of ultraviolet sunlight scattered from Venus' atmosphere near the cloud-tops was found to contain absorption features due to sulfur dioxide (SO_2). It was shown that the SO_2 was being transported upwards from the clouds into sunlight, where photochemistry in the presence of water vapor converted it into sulfuric acid. This is the crucial step in the formation of Venus' sulfuric-acid cloud layers. It was also found that the amount of SO_2, and its rate of upward flow, decreased steadilt
SO_2, and its rate of upward flow, decreased steadily for about 5 years after orbit insertion. This was interpreted as evidence for a massive volcanic injection of sulfur compounds into the atmosphere a shirt period(months or perhaps a year) before orbit insertion. It remains the strongest evidence for active Venusian vulcanism.

c) The nightside of Venus was found to radiate UV emissions from atomic oxygen, indicating the precipitation of energetic electrons into the nightside atmosphere - the Venusian version of the aurorae observed on the earth and Jupiter. Because Venus lacks a magnetic field, its 'aurorae' are diffuse and are not concentrated in polar 'auroral ovals' as they are on Earth and Jupiter. The electrons are diverted from the flow of the charged solar wind past the planet, by the complex and highly variable system of electric currents and weak magnetic fields set up by this flow.

d) Venus was found to possess 'coronae' of energetic (or 'hot') atoms of oxygen, carbon, and nitrogen. The source is the presence of molecular ions (of O_2, NO, and CO) above the exobase. When these ions recombine dissociatively with ambient electrons, they yield 'hot' atoms with energies of a few eV - not enough energy to allow the atoms to escape into interplanetary space, but enough to put them in high ballistic orbits that extend several thousand km above the exobase. The atoms contribute to the escape of gases from Venus in two ways : they may be photionized by EUV sunlight and subsequently swept away by the solar wind's magnetic field; ot they may, when they fall back to the atmosphere, collide with atoms of h, D, or He and eject these atoms into escape trajectories.

e) Measurement of UV light scattered from atoms of oxygen in Venus' thermosphere showed a deficiency of atomic oxygen near the morning terminator as compared to the evening terminator. This was found to be due to the well-known superrotation of Venus' upper atmosphere and the gravity waves excited by the turbulence near the cloud-tops.

These waves propagate upwards, but are attenuated near the evening terminator where their phase speed is matched by the combination of the superrotation and the solar-driven day-to-night winds. At the morning terminator, the superrotation and the day-to-night winds tend to cancel and the net wind does not match the gravity-wave phase speed. The waves therefor enter the thermosphere where they break and dissipate. The resulting turbulence transports atomic species downwards, reducing the atomic oxygen concentration as observed.

f) Comet Halley was observed throughout its perihelion passage, at a time when the comet could not be observed from Earth because of its proximity to the Sun. A spin-scan image of Halley's hydrogen coma was obtained, and its rate of production of H was measured from late December 1985 through early March of 1986. From these data, Halley's water loss rate was found to peak near 50 tons/sec shortly after perihelion and to remain high for another 2-3 weeks.

3. SUMMARY

The Ultraviolet Spectrometer investigation on the Pioneer Venus Orbiter mission was extremely successful. The instrument was designed, built and tested at CU/LASP and delivered on time and within budget. The spacecraft and its instruments were required to operate for 243 days in Venus orbit. OUVS operated successfully for a further 13 years with only minor problems. The major scientific results listed above that deal with Venus were all unexpected and significant discoveries. The Comet Halley observations came about because of a favorable alignment of Halley, the Sun, and Venus, and were an important contribution to the international study of this comet. The scientific results of the OUVS investigation are to be found in the 41 papers listed in section 4 below. OUVS data provided material for 6 PhD and one MS dissertations, listed in section 5 below.

4. BIBLIOGRAPHY.
41 published papers reporting or using PVOUVS results.

Hoffman, J. H., G. M. Keating, H. Niemann, V. Oyama, J. Pollack, A. Sieff, A. I. Stewart, and U. von Zahn, 1977, "Composition and Structure of the Atmosphere of Venus", Space Sci. Rev., 20, 307-327

Tomasko, M. G., R. Boese, A. P. Ingersoll, A. A. Lacis, S. S. Limaye, J. B. Pollack, A. Sieff, A. I. Stewart, V. Suomi, and F. W. Taylor, 1977, "The Thermal Balance of the Atmosphere of Venus", Space Sci. Rev., 20, 389-412

Cravens, T. E., A. F. Nagy, R. H. Chen, and A. I. Stewart, 1978, "The Ionosphere and Airglow of Venus : Prospects for Pioneer Venus", Geophys. Res. Lett., 5, 613-616

Stewart, A. I., D. E. Anderson, Jr., L. W. Esposito, and C. A. Barth, 1979, "Ultraviolet Spectrometry of Venus : Initial Results from the Pioneer Venus Orbiter", Science, 203, 777-779

Stewart, A. I. and C. A. Barth, 1979, "Ultraviolet Night Airglow of Venus", Science, 205, 59-62

Pollack, J. B., B. Ragent, R. Boese, M. G. Tomasko, J. Blamont, R. G. Knollenberg, L. W. Esposito, A. I. Stewart, and L. Travis, 1979, "Nature of the Ultraviolet Absorber in the Venus Clouds : Inferences Based on Pioneer Venus Data", Science, 205, 76-79

Esposito, L. W., J. R. Winick, and A. I. Stewart, 1979, "Sulfur Dioxide in the Venus Atmosphere : Distribution and Implications", Geophys. Res. Lett., 6, 601-604

Stewart, A. I. F., 1980, "Design and Operation of the Pioneer Venus Orbiter Ultraviolet Spectrometer", I. E. E. E. Trans. on Geosci. Remote Sensing, GE-18, 65-70

Durrance, S. T., C. A. Barth, and A. I. F. Stewart, 1980, "Pioneer Venus Observations of the Venus Dayglow Spectrum 1250 - 1430 A", Geophys. Res. Lett., 7, 222-224

Winick, J. R. and A. I. F. Stewart, 1980, "Photochemistry of SO2 in Venus' Upper Cloud Layers", J. Geophys. Res., 85, 7849-7860

Stewart, A. I. F., J.-C. Gerard, D. W. Rusch, and S. W. Bougher, 1980, "Morphology of the Venus Ultraviolet Night Airglow", J. Geophys. Res., 85, 7861-7870

Knollenberg, R., L. Travis, M. Tomasko, P. Smith, B. Ragent, L. Esposito, D. McCleese, J. Martonchik, and R. Beer, 1980, "The Clouds of Venus : a Synthesis Report", J. Geophys. Res., 85, 8059-8081

Pollack, J. B., O. B. Toon, R. C. Whitten, R. Boese, B. Ragent, M. Tomasko, L. Esposito, L. Travis, and D. Wiedman, 1980, "Distribution and Source of the UV Absorption in Venus' Atmosphere", J. Geophys. Res., 85, 8141-8150

Esposito, L. W., 1980, "Ultraviolet Contrasts and the Absorbers Near the Venus Cloud Tops", J. Geophys. Res., 85, 8151-8157

Esposito, L. W., 1981, "Absorbers Seen Near the Venus Cloud Tops from Pioneer Venus", Adv. Space Res., 1, 163-166

Nagy, A. F., T. E. Cravens, J.-H. Yee, and A. I. F. Stewart, 1981, "Hot Oxygen Atoms in the Upper Atmosphere of Venus", Geophys. Res. Lett., 8, 629-632

Gerard, J.-C., A. I. F. Stewart, and S. W. Bougher, 1981, "The Altitude Distribution of the Venus Ultraviolet Nightglow and Implications for Vertical Transport", Geophys. Res. Lett., 8, 633-636

Esposito, L. W. and L. D. Travis, 1982, "Polarization Studies of the Venus UV Contrasts : Cloud Height and Haze Variability", Icarus, 51, 374-390

Meier, R. R., D. E. Anderson, Jr., and A. I. F. Stewart, 1983, "Atomic Oxygen Emissions Observed from Pioneer Venus", Geophys. Res. Lett., 10, 214-217

Esposito, L. W., 1984, "Sulfur Dioxide : Episodic Injection Shows Evidence for Active Venus Vulcanism", Science, 223, 1072-1074

Esposito, L. W., 1985, "Long Term Changes in Venus Sulfur Dioxide", Adv. Space Res., 5, no. 9, 85-90

Paxton, L. J., D. E. Anderson, Jr., and A. I. F. Stewart, 1985, "The Pioneer Venus Orbiter Ultraviolet Spectrometer Experiment : Analysis of Hydrogen Lyman Alpha Data", Adv. Space Res., 5, 129-132

Scarf, F. L., S. Neumann, L. H. Brace, C. T. Russell, J. G. Luhmann, and A. I. F. Stewart, 1985, "Current-Driven Plasma Instabilities and Auroral-type Particle Acceleration at Venus", Adv. Space Res., 5, 185-191

Paxton, L. J., 1985, "Pioneer Venus Orbiter Ultraviolet Spectrometer Limb Observations : Analysis and Interpretation of the 166- and

156-nm Data", J. Geophys. Res., 90, 5089-5096

Paxton, L. J. and R. R. Meier, 1986, "Reanalysis of Pioneer Orbiter Ultraviolet Spectrometer Data : OI 1304 Intensities and Atomic Oxygen Densities", Geophys. Res. Lett., 13, 229-232

Combi, M. R., A. I. F. Stewart, and W. H. Smyth, 1986, "Pioneer Venus Lyman-alpha Observations of Comet P/Giacobini-Zinner and the Life Expectancy of Cometary Hydrogen", Geophys. Res. Lett., 13, 385-388

Phillips, J. L., A. I. F. Stewart, and J. G. Luhmann, 1986, "The Venus Ultraviolet Aurora : Observations at 130.4 nm", Geophys. Res. Lett., 13, 1047-1050

Ajello, J. M., A. I. Stewart, G. E. Thomas, and A. Graps, 1987, "Solar Cycle Study of Interplanetary Lyman-Alpha Variations : Pioneer Venus Orbiter Sky Background Results", Astrophys. J., 317, 964-986

Stewart, A. I. F., 1987, "Pioneer Venus measurements of H, O, and C Production in Comet Halley near Perihelion", Astron. Astrophys., 187, 369-374

Paxton, L. J., D. E. Anderson, Jr., and A. I. F. Stewart, 1988, "Analysis of Pioneer Venus Orbiter Ultraviolet Spectrometer Lyman-Alpha Data from near the Subsolar Region", J. Geophys. Res., 93, 1766-1772
Correction, 1988, J. Geophys. Res., 93, 11551

Esposito, L. W., M. Copley, R. Eckert, L. Gates, A. I. F. Stewart, and H. Worden, 1988, "Sulfur Dioxide at the Venus Cloud Tops 1978-1986", J. Geophys. Res., 93, 5267-5276

LeCompte, M. A., A. I. F. Stewart, and L. J. Paxton, 1989, "Analysis and Interpretation of Observations of Airglow at 297 nm in the Venus Thermosphere", J. Geophys. Res., 94, 208-216

Lallement, R. and A. I. F. Stewart, 1990, "Out-of-Ecliptic Lyman-Alpha Observations with Pioneer-Venus : Solar Wind Anisotropy Degree in 1986", Astron. Astrophys., 227, 600-608

Ajello, J.M., 1990, "Solar Minimum Lyman-alpha Sky Background Observations from Pioneer Venus Orbiter Ultraviolet Spectrometer : Solar Wind Latitude Variation", J. Geophys. Res., 95, 14855-14861

Bougher, S. W., J.-C. Gerard, A. I. F. Stewart, and C. G. Fesen, 1990, "The Venus Nitric Oxide Airglow : Model Calculations Based on the Venus Thermospheric General Circulation Model", J. Geophys. Res., 95, 6271-6284

Fox, J. L. and A. I. F. Stewart, 1991, "The Venus Ultraviolet Aurora : a Soft Electron Source", J. Geophys. Res., 96, 9821-9828

Smyth, W. H., M. R. Combi, and A. I. F. Stewart, 1991, "Analysis of the Pioneer-Venus Lyman-Alpha Image of the Hydrogen Coma of Comet P/Halley", Science, 253, 1008-1010

Pryor, W. R., J. M. Ajello, C. A. Barth, C. W. Hord, A. I. F. Stewart, K. E. Simmons, W. E. McClintock, B. R. Sandel, and D. E. Shemansky, 1992, "The Galileo and Pioneer Venus Ultraviolet Spectrometer Experiment : Solar Lyman-Alpha Latitude Variation at Solar Minimum from Interplanetary Lyman-Alpha Observations", Astrophys. J., 394, 363-377

Alexander, M.J., 1992, "A Mechanism for the Venus Thermospheric

Superrotation", Geophys. Res. Lett., 19, 2207-2210

Alexander, M. J., A. I. F. Stewart, S. C. Solomon, and S. W. Bougher, 1993, "Local-Time Asymmetries in the Venus Thermosphere", J. Geophys. Res., 98, 10849-10871

Kasprzak, W. T., G. M. Keating, N. C. Hsu, A. I. F. Stewart, W. B. Colwell, and S. W. Bougher, 1996, "Solar Cycle Behavior of the Thermosphere", in "Venus II" (D. M. Hunten et al., eds.), 225-258, Univ. of Arizona Press, Tucson

5. HIGHER DEGREES

7 PhD and MS degrees gained using PVOUVS data.

Ph.D. S. T. Durrance
University of Colorado, 1980
"The Carbon Monoxide Fourth Positive Bands in the Venus Dayglow"

M.S. S. W. Bougher
University of Colordao, 1980
"The Ultraviolet Night Airglow of Venus - MorPhology and Implications"

Ph.D. L. J. Paxton
University of Colorado, 1983
"Atomic Carbon in the Venus ThermosPhere : Observations and Theory"

Ph.D. R. A. L. Swanson
University of Colorado, 1983
"Carbon Monoxide Fourth Positive Ultraviolet Airglow Emissions on Venus"

Ph.D. M. A. LeCompte
University of Colorado, 1984
"Analysis and Interpretation of Observations of Airglow at 297 nm in the Venus ThermosPhere"

Ph.D. M. J. Alexander
University of Colorado, 1992
"The Venus 130-nm Dayglow as a Diagnostic of ThermosPheric Structure and Dynamics"

Ph.D. W. B. Colwell
University of Colorado, 1997
"Venus Lyman-alPha : a MorPhological and Radiative Transfer Analysis"